BELLCOMM, INC.

SUBJECT: S-IVB Restart Requirements. Case 310

DATE: April 14, 1967

FROM: R. L. Wagner

ABSTRACT

This memorandum presents material in support of developing a requirement on the minimum restart time for the Saturn V S-IVB stage as used for lunar missions. The major mission considerations are as follows:

(1) To achieve daily launch windows (a major reason for using the earth parking orbit mode) it is not necessary to restrict the orbit in which translunar injection occurs.

(2) Flexibility in orbital timelines is improved if translunar injection can be caused to occur in the first, second or third orbit as required.

(3) Minimum restart times of 35 minutes and 80 minutes are "milestones" of particular significance. The former supports first orbit Pacific injections and the latter supports second orbit Atlantic injections.

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MEMORANDUM FOR FILE

Introduction

This memorandum presents material in support of developing a requirement on the minimum restart time for the Saturn V S-IVB stage.

Background

The restart of the S-IVB in earth parking orbit is required so as to allow missions to the moon on any day of the month or year (as far as propulsion is concerned). Otherwise direct launches must be used and these are useful only for a few days each month when the moon is near its extreme southern location. These direct launch opportunities do not generally occur in synchronism with preferred lighting for LM landing on the moon.

The intercenter panels became concerned with the minimum restart time (time from termination of the first S-IVB burn at earth orbit insertion until the ignition of the S-IVB for translunar injection) several years ago. The time was originally quoted by MSFC representatives as 300 seconds which was understood to be that period during which an automatic sequencer was controlling events leading to ignition. It was some time later that it was first "rumored" that the minimum restart time might be as long as 15 minutes and then later this was raised to something like 40 minutes. It is now realized by mission planners that the J2 engine specification has contained a minimum time requirement of 90 minutes since the very early days of the Apollo program.

The Nature of the Restart Requirements

The basic requirement for earth orbital coast is to provide potential launch windows every day (only propulsion being considered). This requirement can be satisfied by a continuous restart capability during <u>any</u> single, complete, earth parking orbit revolution (about 90 minutes).

Hardware checkout, astronaut timeline, and real time mission flexibility considerations enter in to influence which of the three possible earth parking orbits the restart (and translunar injection) shall occupy. These "timeline" considerations are sufficiently uncertain so as to provide only a general guide for "flexibility" in restart times. It is clear that it would be desirable to be able to restart immediately after insertion into earth parking orbit and to have this capability continuously to the end of the third full orbit. It is difficult to find more tangible timeline requirements to use in a tradeoff with the "cost" of engine modifications to achieve various minimum restart times.

Early injections are generally desirable for reasons of minimizing fuel boiloff (payload loss), guidance platform drift and S-IVB lifetime requirements.

There are certain features, based on orbit mechanics considerations, which suggest discrete restart time milestones. Figure 1 has been prepared to show the sensible worst case coast times in earth parking orbit. The coast time is defined as the time from earth parking orbit insertion until translunar injection ignition, and this exactly equals the restart time in which the engine man is interested. Coast times are shown in Figure 1 as a function of the day of launch for one lunar month. This cycle repeats without significant change during the period 1968 through 1970. In general six coast times are possible each day: three for the Atlantic launch window (corresponding to injection* on each of three orbital passes) and three for the Pacific launch window.

The coast time varies with launch azimuth also and is shortest for the high launch azimuth values. The change in coast time during the launch window is approximately one sixteenth of the launch window duration. For a 4.6-hour window the coast time variation is about 17 minutes which is the approximate width of the coast time "band" between the 72° and 108° launch azimuth curves on Figure 1.

* The ideal launch time is different for each one of these injection opportunities and therefore the parking orbit orientation in inertial space is different for each. To achieve injection possibilities from two successive revolutions in the same parking orbit, a compromise orbit plane orientation is selected and a plane change is made at injection.

Several observations are in order based on Figure 1. To make available all second and third orbit restart possibilities the 90-minute requirement would have to be revised downward slightly (to about 80 minutes). The next milestone of this sort is the Pacific injection opportunity on the first orbit. To achieve this requires a minimum restart (coast) time of about 35 minutes. There is a natural partitioning of the coast times for successive injection opportunities. Whereas all first orbit Pacific injections are covered with about 35 minutes minimum coast time, the coast must be reduced to about 20 minutes before any Atlantic launch windows are available. The value of reducing coast time to 20 minutes and beyond is increasingly subjective and the geometry is such that Atlantic injections could only be made available on a regular basis by including direct injections and very short coast times.

Going beyond the general considerations outlined above makes the conclusions more dependent on the specific mission and/or launch date. A few observations are listed below:

1. The LM lighting constraint as currently seen requires the sun to be between 7° and 20° above the eastern horizon at LM landing. This constraint is met at a given lunar landing site once each 29.5 days. If the earth orbit coast times are plotted for these cases alone, curves like those in Figure 1 again result except that the scale on the abscissa is one year. The left edge of the abscissa corresponds to September (approximately) and the minimum coast time for the Pacific window occurs in the early part of the year.

   Based on early site selection data, educated guesses can be made of the window of choice (Atlantic or Pacific) for each month of the year. It appears that the minimum coast time cases probably will be encountered both for Atlantic and Pacific windows.

2. The situation depicted in Figure 1 changes somewhat during an 18.6-year period and is shown for the end of this decade. During 1978 the coast times for any one injection opportunity (e.g., second orbit Pacific) show less spread. Whereas Figure 1 shows first orbit Pacific coast times ranging from about

35 minutes to 80 minutes, the range would be about 40 minutes to 75 minutes in 1978. It follows that the partitioning of useful coast times for successive injection types becomes more pronounced in the 1978 period. The minimum coast time requirements for similar cases are less severe in 1978.

Conclusions:

1. Timeline flexibility arguments support a continuous capability including very short minimum coast times (which would allow linking with direct injection opportunities in a smooth progression) and extending to the 4.5-hour maximum time in orbit.

2. Short coast times are desirable for reasons of fuel boiloff, guidance platform drift and S-IVB lifetime.

3. An 80-minute restart time supports any second orbit injection.

4. A 35-minute restart time supports any first orbit Pacific injection.

5. A 20-minute restart time is required to support the full launch window for the longest coast first orbit Atlantic injection (the first available window as coast time is reduced). Therefore, coast times between 20 and 35 minutes are of relatively little interest for the lunar landing application.

6. Direct injections (zero coast time) are required to achieve all first orbit Atlantic injection opportunities.

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Attached
  Figure 1

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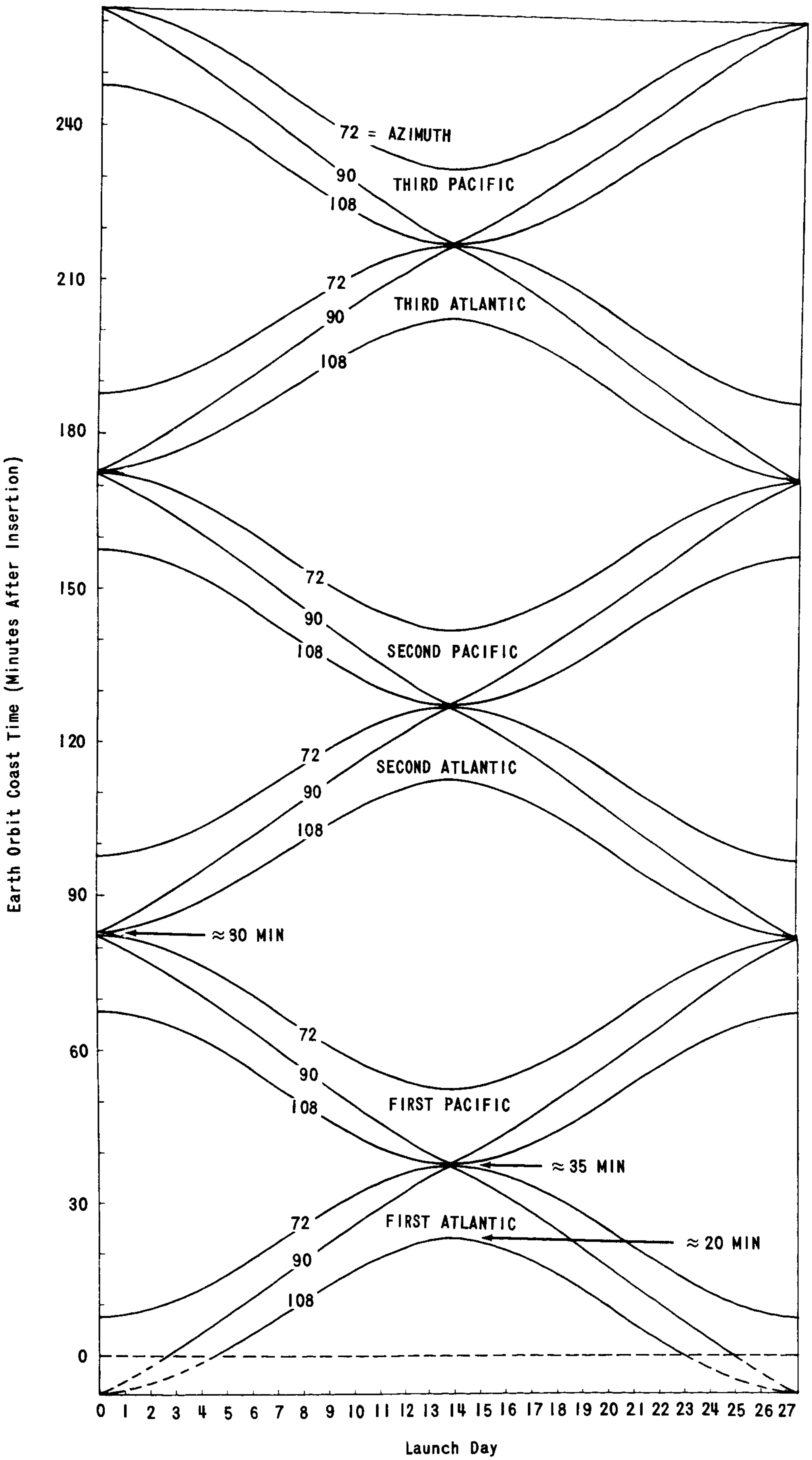

FIGURE 1 - EARTH PARKING ORBIT COAST TIMES FOR "WORST CASE" FREE RETURN TRAJECTORIES (1968-1970)